TYPES OF STRATIGRAPHIC OIL POOLS IN VENANGO SANDS OF NORTHWESTERN PENNSYLVANIA

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TYPES OF STRATIGRAPHIC OIL POOLS IN VENANGO SANDS OF NORTHWESTERN PENNSYLVANIA[1]

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ABSTRACT

A detailed study of the Venango district conducted during the past 5 years by the Pennsylvania Topographic and Geologic Survey has shown that all the oil-producing areas of that district are primarily stratigraphic. They may be classified, on the basis of shape and trend, into three types, each of which is confined to the upper, middle, or lower sandy formation of the Venango group. The first type is characterized by small irregular pools tending to be aligned approximately perpendicular to the ancient shore line. The second type is characterized by more uniform, sheet-like sands which pinch out abruptly along a smooth and fairly straight edge parallel with the ancient shore line. The third type is characterized by long, narrow, and in many places very pebbly bars which are either single or multiple and approximately parallel with the ancient shore line. Pools typical of each of these types are described.

INTRODUCTION

It is common knowledge that the oldest oil and gas fields in petroleum history are located in northwestern Pennsylvania. It has long been known, or at least strongly suspected, that these pools are primarily of the stratigraphic type. John F. Carll made, in 1874, a general structure map for the district near Titusville[4] which showed the absence of any relation between structure and oil accumulation. He recognized clearly that the localization of the pools was determined by the physical characteristics of the sand. Except for this early work of Carll, and the various republications of his astute conclusions, very little geological information on this historically famous and still valuable oil region has, until recently, been assembled.

Realizing the inadequate understanding of these pools, S. H. Cathcart, then with the Pennsylvania Topographic and Geologic Survey, began, in 1936, a detailed geologic survey of them. The plan was to assemble all the available data on the area—the well records, core data, production records, *et cetera*—and to attempt interpretation of these data in the light of modern petroleum geology. When Cathcart left the Survey in 1937 the project was continued by the writers.

[1] Published by permission of the State geologist of Pennsylvania. Manuscript received, April 19, 1941.

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[3] Pennsylvania Topographic and Geologic Survey.

[4] John F. Carll, "The Geology of Venango County," *Second Pennsylvania Geol. Survey Rept. I* (1875), p. 19.

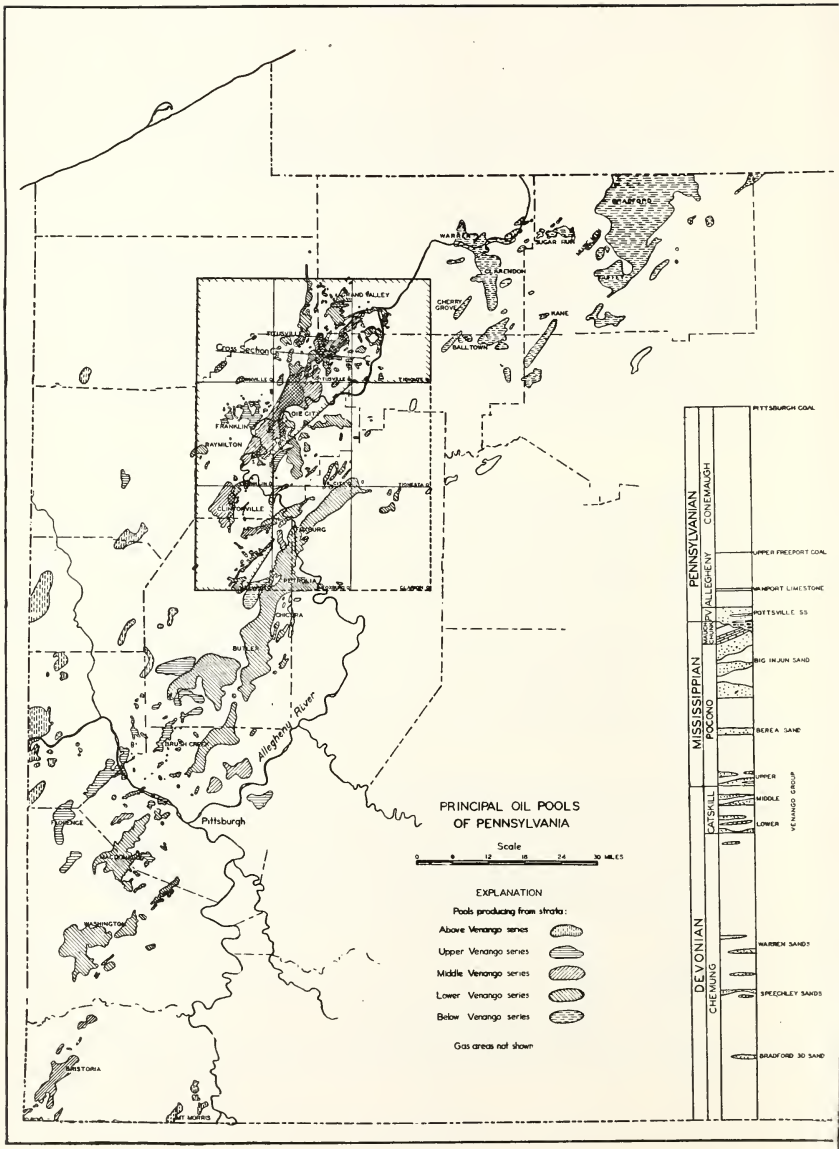


FIG. 1.—Map of principal oil pools of Pennsylvania showing location of area studied and line of section *CC*.

This survey has developed into a major undertaking. More than 15,000 well records have been collected, the wells located, and elevations determined. Mapping of the surface structure and stratigraphy, estimation of reserves, and consideration of production practice are parts of the project. The work is not completed but it is sufficiently advanced so that the different types of pools in the area are known. The purposes of this paper are to indicate the different stratigraphic types in the Venango sands, to illustrate each, and to present certain data concerning them.

The area under particular consideration is generally known as the Venango district of Pennsylvania. It extends from the Butler County cross belt, in central Butler County, Pennsylvania, northeastward through the Triumph Streak of Warren County, Pennsylvania. Its limitations are indicated in Figure 1.

The productive sands of this district lie at shallow depths—generally less than 1,000 feet. The pools discussed were discovered during the period extending from 1859 to about 1900. They were found through random drilling, prospecting near oil seeps, or through following trends. Many of them have been partly or entirely abandoned one or more times and then reclaimed through drilling between old locations, de-watering, air or gas drive, or other methods. The present average daily oil production of the wells is probably less than $\frac{1}{4}$ barrel. Although cores or core analyses are available for many of the newer wells, especially in the northern part of the district, most of the well logs record only the depth to the top and to the bottom of the productive sand.

Stratigraphy

The exposed and near-surface rocks of the Venango district range in age from upper Devonian to upper Pennsylvanian (Table I). The older of the exposed rocks crop out only in the northern part of the district because the southward regional dip carries them below drainage level in the southern part. The oil-productive First and Second sands crop out in the valley of the Allegheny River in the northeastern part of the district.

Pennsylvanian System

As indicated in Table I, the upper part of the Pennsylvanian, the Pittsburgh series, consists predominantly of shale, and the lower part, the Pottsville series, is principally massive, lenticular sandstone. These massive sandstones have strongly influenced the topography. The Olean conglomerate, at the base of the Pennsylvanian, thins southward and is absent in the southern two-thirds of the district.

TABLE I

GENERALIZED STRATIGRAPHIC SECTION OF VENANGO DISTRICT, PENNSYLVANIA

Classification	*Description*	*Thickness (Feet)*
	Exposed	
PENNSYLVANIAN SYSTEM		
Pittsburgh series		
Conemaugh group	Shale and subordinate thin-bedded sandstones. Only lower 250 feet preserved in Venango district	250
Allegheny group	Shale and subordinate sandstone and limestone. Contains valuable coal and clay beds	300
Pottsville series	Massive coarse-grained sandstones and subordinate shale, coal, clay and limestone. Sandstones, designated in descending order the Homewood, upper and lower Connoquenessing, are productive Salt sands of southern Pennsylvania. At base, in northern third of district, is Olean conglomerate	250
~~Major unconformity separates Pennsylvanian and Mississippian~~~		
MISSISSIPPIAN SYSTEM		
Kinderhook series		
"Pocono" group	Massive coarse-grained sandstone and subordinate shale members. Thins northward because of unconformity at top. Consists, in descending order, of Burgoon sandstone, Patton shale, and Shenango formation	0–300
Cuyahoga group	Shale and interbedded argillaceous or calcareous sandstones. Becomes increasingly sandy upward	150
Oil Lake series		
Berea group		
Corry sandstone	Uniform, medium-grained, light gray sandstone. Principal key bed of Venango district	30
Cussewago group	Dark shale and fine-grained sandstone	80
DEVONIAN SYSTEM		
Conewango series		
Riceville group	Dark gray and reddish brown shale. Upper "red rock" of well records	70–110
Venango group		
First sand	Fine to coarse sandstone and subordinate shale and sandy shale	75–120
Saegerstown shale	Dark gray shale with thin and local lentils of fine-grained sandstone	50
Second sand	An upper, the Red Valley, and lower, the Second, fine- to coarse-grained sandstone separated by shale	45–70
	Not Exposed	
Amity shale	Gray shale	55–70
Third sand	Interbedded lenticular fine- to coarse-grained or pebbly sandstones and shales. Contains two principal sands: Third Stray above and Third below	75–110

The Pennsylvanian rests unconformably on the Mississippian. This unconformity is a dominant feature of the stratigraphic column throughout western Pennsylvania. The rocks below the unconformity were tilted southward, probably folded slightly, and truncated by erosion before the Pottsville was deposited.

MISSISSIPPIAN SYSTEM

The stratigraphy of the Mississippian is complex in western Pennsylvania and the classification given in Table I, especially of the "Pocono" group and its subdivisions, is tentative. The system is here considered to extend from the base of the Pottsville to the top of the "red rock" lying about 100 feet above the First sand. As thus considered, it ranges in thickness from about 550 feet in the southern part of the district to about 300 feet in the northern part. This northward decrease in thickness is a result of the unconformity at the top of the system.

DEVONIAN SYSTEM

The Devonian system is several thousand feet thick in the Venango district, but only the upper 400 feet, approximately, of this system is under consideration in this paper. The Conewango series constitutes this upper part of the Devonian and contains the Venango group, in which occur the principal oil and gas sands of the district. Sands below the Venango group are productive locally in the district but are not discussed in this paper.

VENANGO GROUP

The Venango group is 330–350 feet thick and consists of alternating sand and shale members. The sands are discontinuous, lenticular bodies (section, Fig. 2). Their correlation in the area of their extent is best accomplished through detailed tracing from well to well or through the use of electric logs (electric-log section *BB*, Fig. 3).

Although no single sandstone bed extends over the entire district, there are three persistent sandy zones or formations, separated by shale. Following the terminology of the drillers, these sandy zones are designated, in descending order, the First, Second, and Third sands. Within each of these formations, the sand members may lens out or combine, but the shale intervals between formations are fairly constant, and sand members of one formation do not, within the district, combine with members of another formation.

Significant features common to all the Venango sands are listed in the

following paragraphs. Differences between the sands of the three formations are given later under the discussion of the three types of pools.

All the productive Venango sands of the district lie in a northeast-trending belt about 50 miles long and in few places as much as 10 miles wide. All the sands become fine and shaly toward the northwest. In gen-

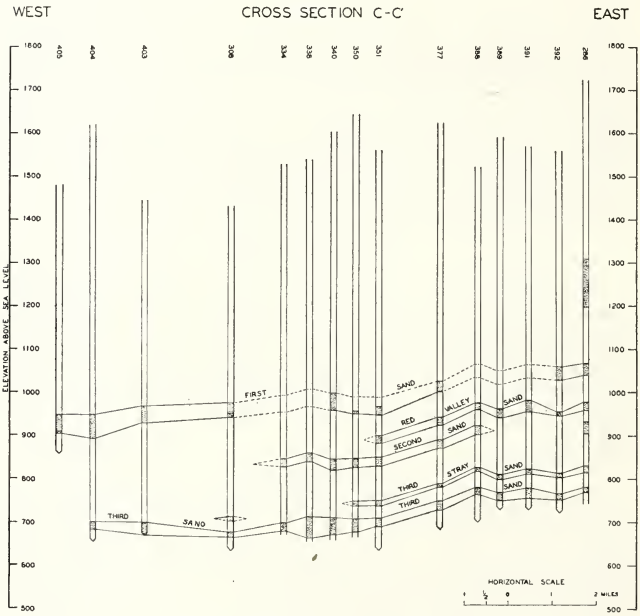


FIG. 2.—Cross section along line *CC* of Figure 1.

eral they also become fine and shaly for a short distance southeast. Six to 10 miles southeast of the limits of the Venango belt lies the similar Butler-Clarion belt within which the Venango group is productive of oil. At longer distances southeast the conditions are not so well known, but the entire section is thought to thicken and to include new beds. The sand bodies of the Venango belt are generally thickest and most pebbly near their northwestern limit.

The Venango sands consist predominantly of clear quartz. Feldspars are rare but muscovite is abundant. Heavy minerals are scarce and show few species. Zircon and tourmaline constitute the bulk of the heavy minerals. The tourmalines are of various colors and some show euhedral outgrowths on rounded grains. Barite is locally common and is undoubtedly authigenic. Rutile, anatase, brookite, ilmenite, hematite, limonite, siderite, and pyrite are common. Garnet, chlorite, and zoisite are rare. Andalusite, sillimanite, staurolite, and cyanite are extremely rare or absent. The striking features of the detrital heavy-mineral suite are its constance in percentage and its lack of the less resistant minerals. These indicate that the source of the sands was essentially the same and that this source consisted almost entirely of sedimentary rocks or of a sedimentary series which had been only slightly metamorphosed.

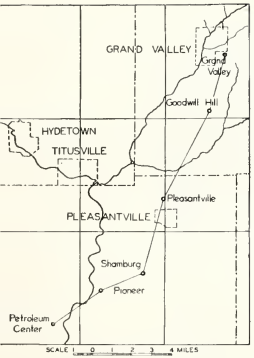
The Venango sands are well cemented by secondary silica. Thin sections show secondary silica outgrowths which partake of the crystal axes of the original quartz grains, and which join the adjacent grains in an irregular manner. Most of the fractures and small cavities are filled with calcite. As a rule, the finer the grain size, the more complete is the secondary silica cementation. Most of the coarser pebble rocks are loose and friable, except where the pebbles are in a fine sand, clay, or ferruginous matrix. In some coarse pebble rocks, small, loose, perfectly euhedral quartz crystals are common.

The water content of the sands ranges from 40 to 60 per cent. In nearly all the pools salt water is produced with the oil, but it is not known in most places whether it is coming from the same beds as the oil or from adjacent strata.

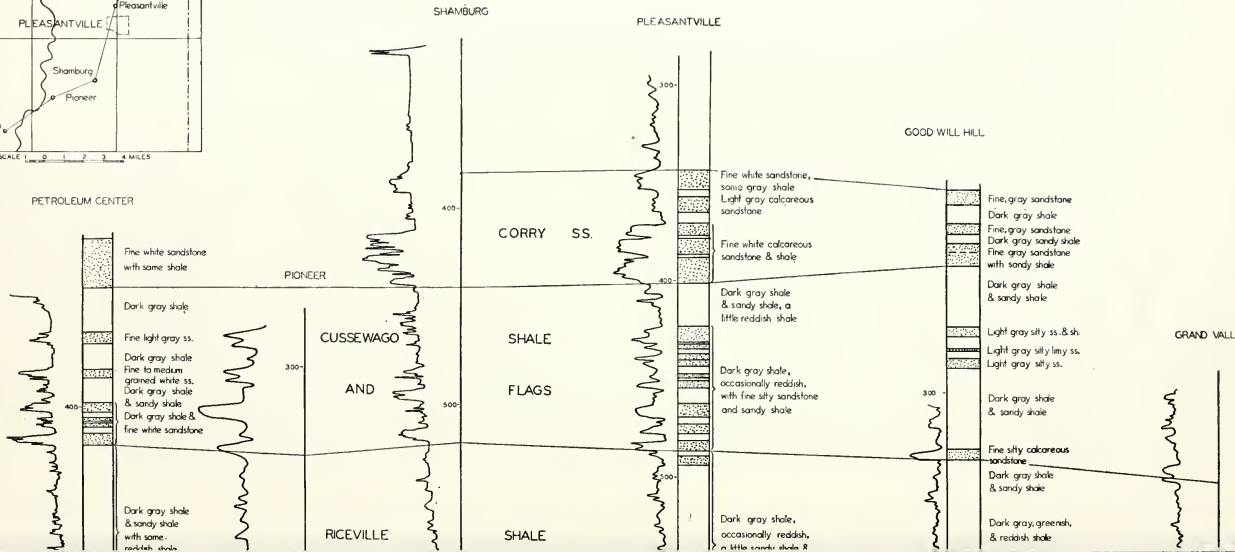
Oil and gas in commercial quantities are found only where there are porous and permeable sands. The converse is almost equally true in this district—that where porous and permeable sands exist oil or gas is present in commercial quantities provided that the sand body is sealed and is sufficiently thick. Where oil is not present, the sand is tight. The comparatively few exceptions to this rule are in the First sand or at structurally low locations in the Second sand.

STRUCTURE

Structurally, the Venango district is in the northwestern part of the Appalachian foreland. This foreland lies west and north of the closely folded and faulted Appalachian Mountains. It is a broad, gentle, spoon-shaped synclinorium, whose long axis extends generally northeast and southwest, and whose lowest part is in northwestern West Virginia.


GRAND VALLEY
Grand Valley
Goodwill Hill
HYDETOWN
TITUSVILLE
Pleasantville
PLEASANTVILLE
Shamburg
Pioneer
Petroleum Center
SCALE 1 0 1 2 3 4 MILES

KEY MAP


PETROLEUM CENTER
Fine white sandstone with some shale
Dark gray shale
Fine light gray ss.
Dark gray shale
Fine to medium grained white ss.
Dark gray shale & sandy shale
Dark gray shale & fine white sandstone
Dark gray shale & sandy shale with some reddish shale
400
PIONEER
CUSSEWAGO AND RICEVILLE
300
SHAMBURG
400
500
CORRY SS.
SHALE FLAGS
SHALE
PLEASANTVILLE
300
400
500
Fine white sandstone, some gray shale
Light gray calcareous sandstone
Fine white calcareous sandstone & shale
Dark gray shale & sandy shale, a little reddish shale
Dark gray shale, occasionally reddish, with fine silty sandstone and sandy shale
Dark gray shale, occasionally reddish, a little sandy shale
GOOD WILL HILL
300
Fine, gray sandstone
Dark gray shale
Fine, gray sandstone
Dark gray sandy shale
Fine gray sandstone with sandy shale
Dark gray shale & sandy shale
Light gray silty ss. & sh.
Light gray silty limy ss.
Light gray silty ss.
Dark gray shale & sandy shale
Fine silty calcareous sandstone
Dark gray shale & sandy shale
Dark gray, greenish, & reddish shale
GRAND VALL

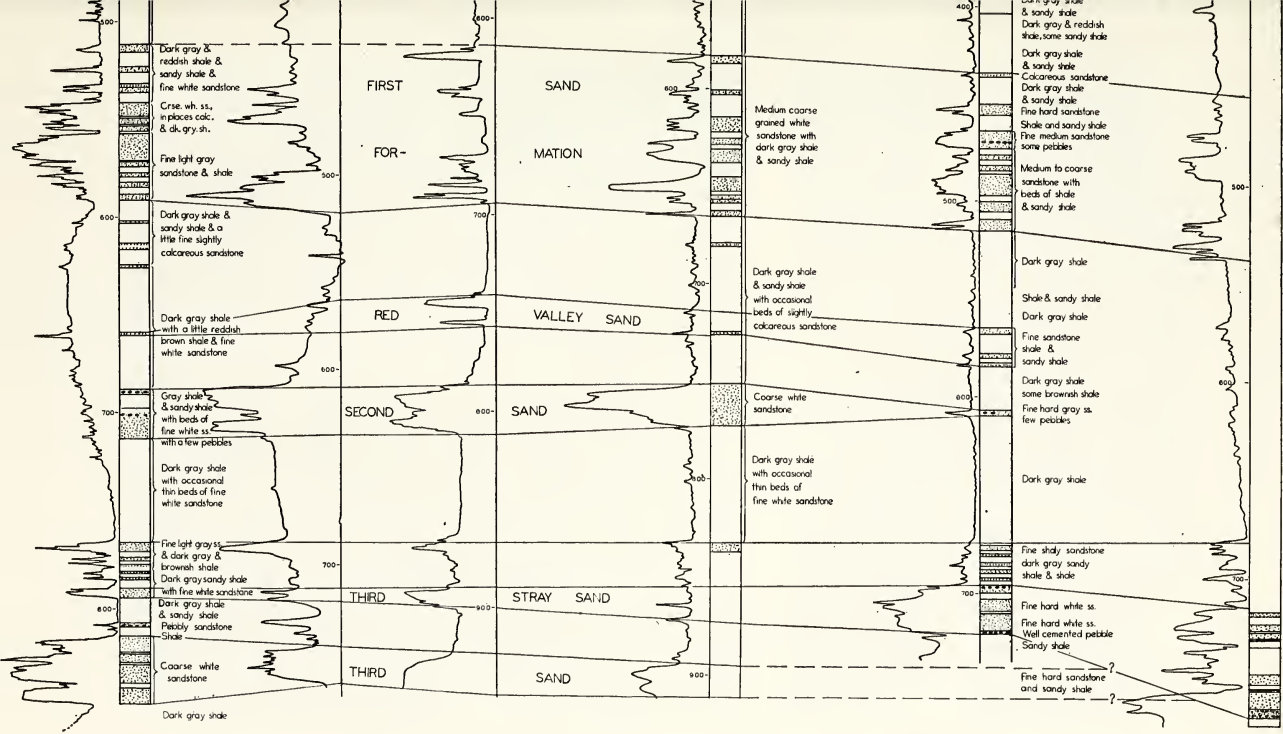
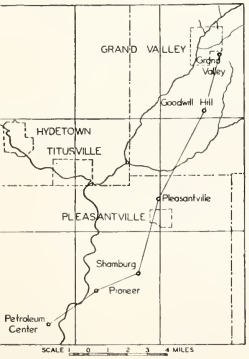
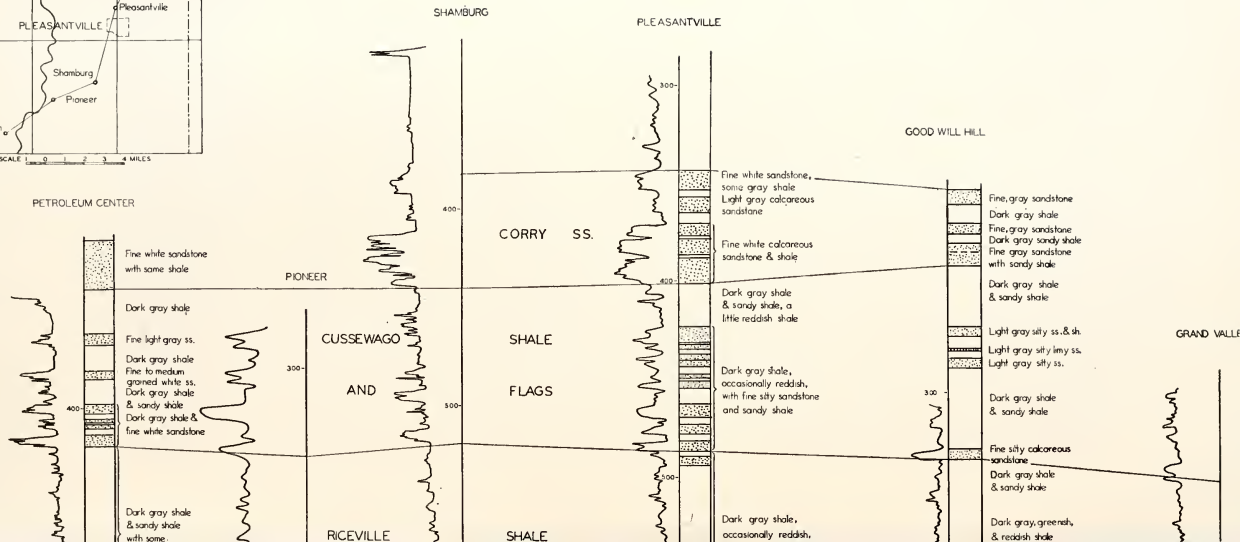


FIG. 3.—Columnar sections in Titusville Quadrangle, based on electric logs, drill cuttings, and cores.


GRAND VALLEY
Grand Valley
Goodwill Hill
HYDETOWN
TITUSVILLE
Pleasantville
PLEASANTVILLE
Shamburg
Pioneer
Petroleum Center
SCALE 1 0 1 2 3 4 MILES

KEY MAP


PETROLEUM CENTER
PIONEER
SHAMBURG
PLEASANTVILLE
GOOD WILL HILL
GRAND VALLE
400
300
500
CORRY SS.
CUSSEWAGO AND RICEVILLE
SHALE FLAGS
SHALE
Fine white sandstone with some shale
Dark gray shale
Fine light gray ss.
Dark gray shale
Fine to medium grained white ss.
Dark gray shale & sandy shale
Dark gray shale & fine white sandstone
Dark gray shale & sandy shale with some
Fine white sandstone, some gray shale
Light gray calcareous sandstone
Fine white calcareous sandstone & shale
Dark gray shale & sandy shale, a little reddish shale
Dark gray shale, occasionally reddish, with fine silty sandstone and sandy shale
Dark gray shale, occasionally reddish,
Fine, gray sandstone
Dark gray shale
Fine, gray sandstone
Dark gray sandy shale
Fine gray sandstone with sandy shale
Dark gray shale & sandy shale
Light gray silty ss. & sh.
Light gray silty limy ss.
Light gray silty ss.
Dark gray shale & sandy shale
Fine silty calcareous sandstone
Dark gray shale & sandy shale
Dark gray, greenish, & reddish shale

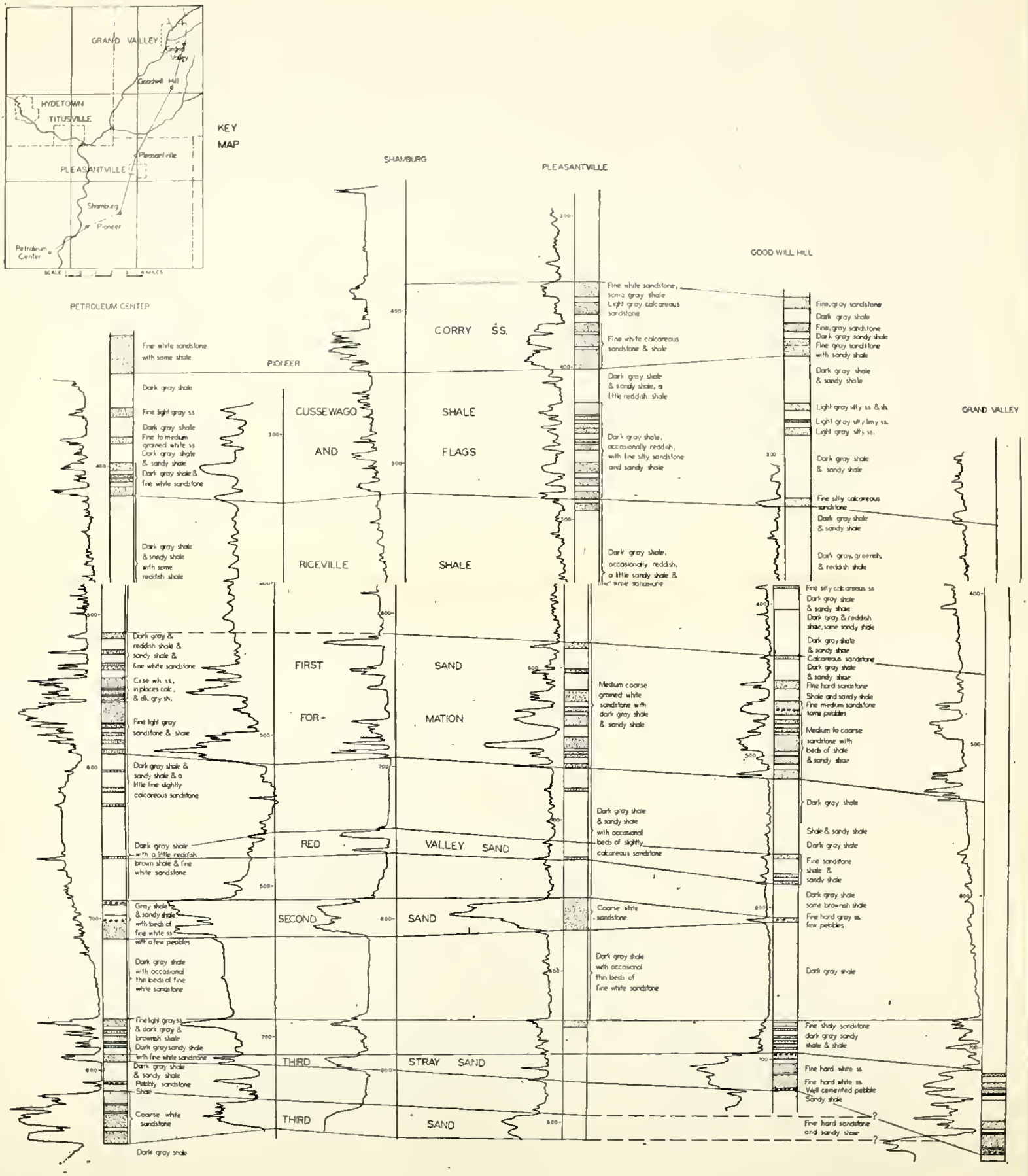


FIG. 3.—Columnar sections in Titusville Quadrangle, based on electric logs, drill cuttings, and cores.

The southeastern part of this foreland basin is characterized by a series of rather prominent northeast-trending folds. In the northwestern part of the foreland, in which lie the oil pools under consideration here, the folds are very gentle and irregular in trend. The dominant structural feature of the Venango district is the southward regional dip of about 20 feet per mile. The detailed structure of the pools here considered is shown by contours on the maps outlining these pools.

TYPES OF VENANGO STRATIGRAPHIC TRAPS

Fundamentally, all the Venango pools belong to the stratigraphic class characterized as sand lenses embedded in less permeable sandstone and shale. They may, however, be subdivided into three distinctly different types on the basis of the shape and trend of the sand bodies. Each type is characteristic of, and confined to, one of the sandy zones or formations.

POOLS OF FIRST SAND

The First sand extends over the entire district as a 75–100-foot zone of shaly sandstone in which are developed irregular lens-shaped bodies of cleaner, coarser, and more porous sand. These more porous beds are, as a rule, of small area and highly irregular. They may occur anywhere from the top to the bottom of the formation, but are more extensive and numerous in the medial and lower parts. They have been variously named according to their general position in the formation and their location in the district (columnar sections, Fig. 3). Largely because of the variable nature of the First sand, it is not possible, at least with the data available, to draw accurate structure or thickness maps for the sand bodies in it.

The term First sand is generally used to designate the oil-producing sand bodies in the lower part of the First sand formation. In Figure 4 are outlined the oil pools of the Titusville Quadrangle producing from this sand. In the northwestern part of this quadrangle the First sand is present, but ordinarily contains only fresh water, which probably entered the sand at former outcrops in the glacial valleys there present. The oil-productive First Sand bodies are limited to the southeastern two-thirds of the quadrangle. It is especially noteworthy that the First Sand pools, as indicated in Figure 4, exhibit a decided tendency toward alignment northwest and southeast. This trend, which is approximately perpendicular to that of the lower Venango sands, is characteristic of the First Sand pools throughout the Venango district. In the Titusville Quadrangle, at least, the sand is more pebbly toward the northwest and finer southeast.

The physical character of the oil is as variable as the sand. The oil

ranges from a straw-yellow color to nearly black, and the A.P.I. gravity ranges from 32° to 52°.

Grand Valley First Sand pool.—The Grand Valley First Sand pool is in the northeastern part of the Titusville Quadrangle, about 3 miles south of the village of Grand Valley. The productive First Sand lenses are very variable, and the thickness recorded in well logs changes greatly within a few hundred feet laterally. The pay beds seem to occur more persistently in the lower part of the sand, but in many places the whole section is shaly and impermeable. The pool has long, narrow lobes with divergent directions, which are probably sand bodies of different stratigraphic position. Core-analysis profiles of two wells about 300 feet apart in the center of the pool are shown in Figure 10. Northwest of the main part of the pool are several smaller scattered productive areas. In most of these, the sand is coarse and pebbly, and some of them have been very productive.

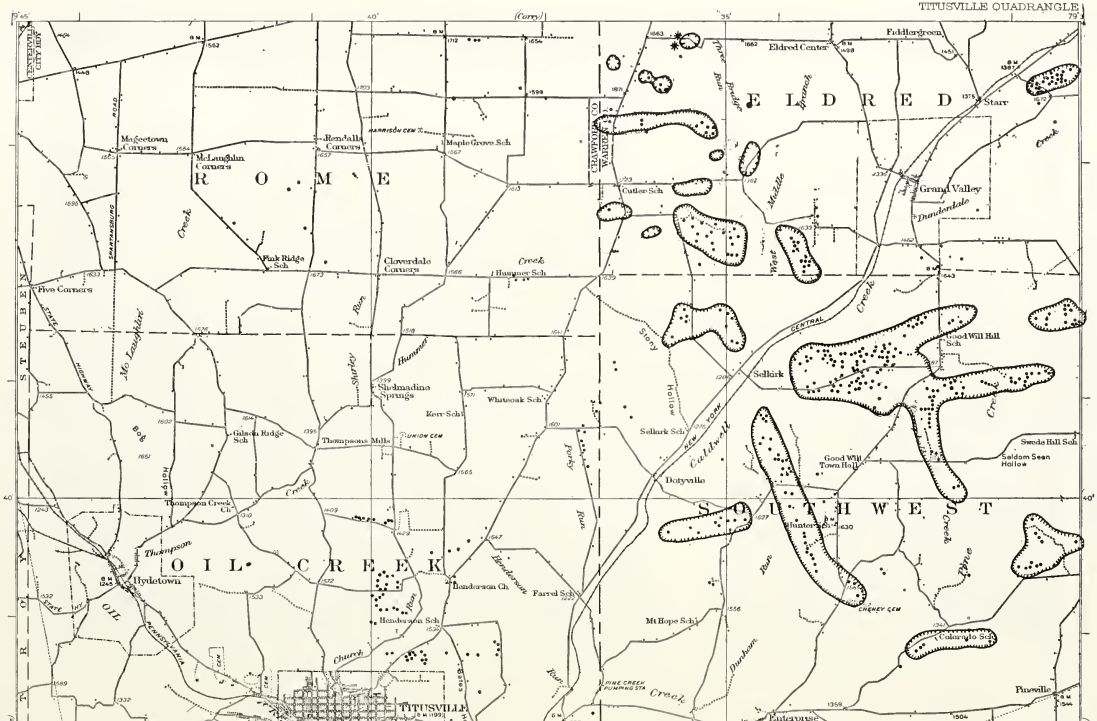
POOLS OF SECOND SAND

The Second Sand formation is the sandy medial part of the Venango group. Where fully developed it consists of two sandstone members, the Red Valley sand at the top, and the Second sand at the bottom, separated by 30 feet of shale. Marine fossils occur in the outcrops at the extreme northeastern part of the district. The two members are the most continuous, sheet-like sands of the Venango group, and are much more uniform in thickness and lithologic character than the other sands. Both have a smooth and fairly straight northwest edge, beyond which the sand is absent. The Second sand extends farther northwest than the Red Valley. They are coarsest and most productive within 3–4 miles of their northwest edge. Toward the southeast they generally become finer in texture and red in color. In the southern part of the district the Second sand consists of two sand members and a medial shale. The lower sand member does not extend into the northern part of the district (Fig. 5).

The permeability of the Second sand is characteristically low, ranging from 10 to 100 millidarcys. The oil from this sand is fairly uniform in its physical properties. It is light to dark green in color, and ranges in gravity from 34° to 38° A.P.I., except in the northern part of the district where it is as high as 45° A.P.I.

The Red Valley sand is best developed in the northern part of the district. It is in most respects similar to the Second sand, but is productive under a smaller area.

Clintonville-Bullion pool.—The Clintonville-Bullion pool (Fig. 6) is in the southern part of the district. The Second sand of this pool ranges up to 50 feet in thickness, but generally only the lower 10 feet is pay sand.


ELDRED
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TITUSVILLE
Eldred Center
Fiddlegreen
Starr
Grand Valley
Pinnacledale
Good Will Hill Sch
Sellark
Sellark Sch
Good Will Town Hall
Swede Hall Sch
Saldom Seen Hollow
Dotyville
Hunter Sch
Cheney Cem
Colorado Sch
Pineville
Mt Hope Sch
Farrel Sch
Henderson Ch
Henderson Sch
Hydetown
Thompson Creek Ch
Thompsons Mills
Union Cem
Gibson Ridge Sch
Kerr Sch
Whitcoak Sch
Shelmadine Springs
Hummer Sch
Cloverdale Corners
Five Corners
Park Ridge Sch
Mc Langhlin Corners
Rendalls Corners
Maple Grove Sch
Cutler Sch
Mageetown Corners
Hannah Cem
Crawford Co
Warren Co
Oil City
Pine Creek Pumping Sta
Caldwell Creek
Story Hollow
Hendersen Run
Parker Run
Dunham Run
Pine Creek
Shorley Run
Hummer Run
Mc Langhlin Run
Thompson Run
Church Run
Middle Branch
West Branch
Central Creek
Pine Creek
Oil Creek
Oil City
Rockland Ave
Hydetown Rd
Shakesburg Rd
Mc Langhlin Rd
Road
Creek
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Hollow
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Dunham
Farrel
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Cheney
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Pineville
Eldred Center
Starr
Grand Valley
Pinnacledale
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Sellark
Dotyville
Hydetown
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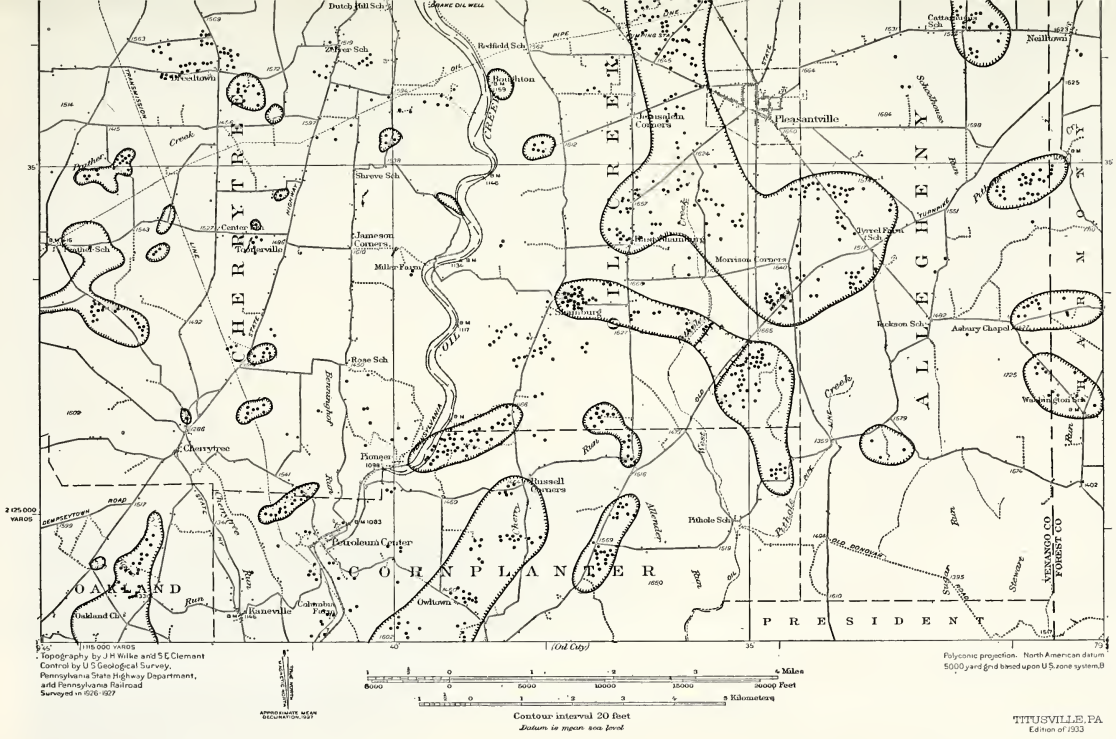
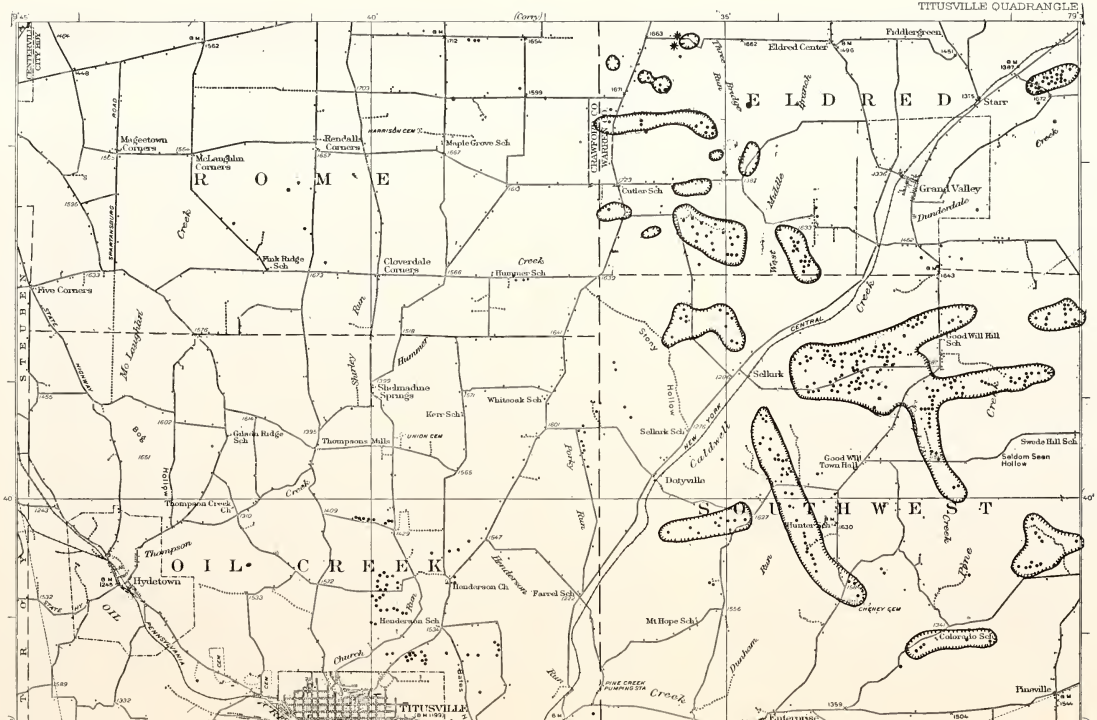


FIG. 4.—Map of Titusville Quadrangle showing areas producing oil from First sand. Limits of production shown by closely hachured lines; abandoned areas by widely hachured lines; wells whose logs record sand at this horizon and used in compiling this map, dots.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Starr
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McLaughlin Corners
Rendalls Corners
Maple Grove Sch
Cutler Sch
Grand Valley
Dunderdale
Pink Ridge Sch
Cloverdale Corners
Hunter Sch
Five Corners
Good Will Hill Sch
Sellark
Sladmadine Springs
Kerr Sch
Whitcoak Sch
Sellark Sch
Good Will Town Hall
Swede Hill Sch
Seldom Seen Hollow
Gibson Ridge Sch
Thompsons Mills
Dotyville
Thompson Creek Ch
Hydetown
Hunter Sch
Henderson Ch
Henderson Sch
Farrel Sch
Mt Hope Sch
Colorado Sch
Pinnville
Cutler
Cranberry
Stoney Hollow
Caldwell
Middle Branch
West Branch
Central Creek
Oil Creek
Thompson
Church
Pine Creek
Dunham
Henderson
Hammond
Shirley
Perry
Bog
Mc Laughlin
Pine Creek Pumping Sta
Cheney Cem
Union Cem
Harrison Cem
Crawford Co
Warren Co
Stoneman Road
Titusville Road
Pennsylvania Railroad
Oil City Branch
Pennsylvania Railroad
Oil City Branch
Pennsylvania Railroad
Oil City Branch

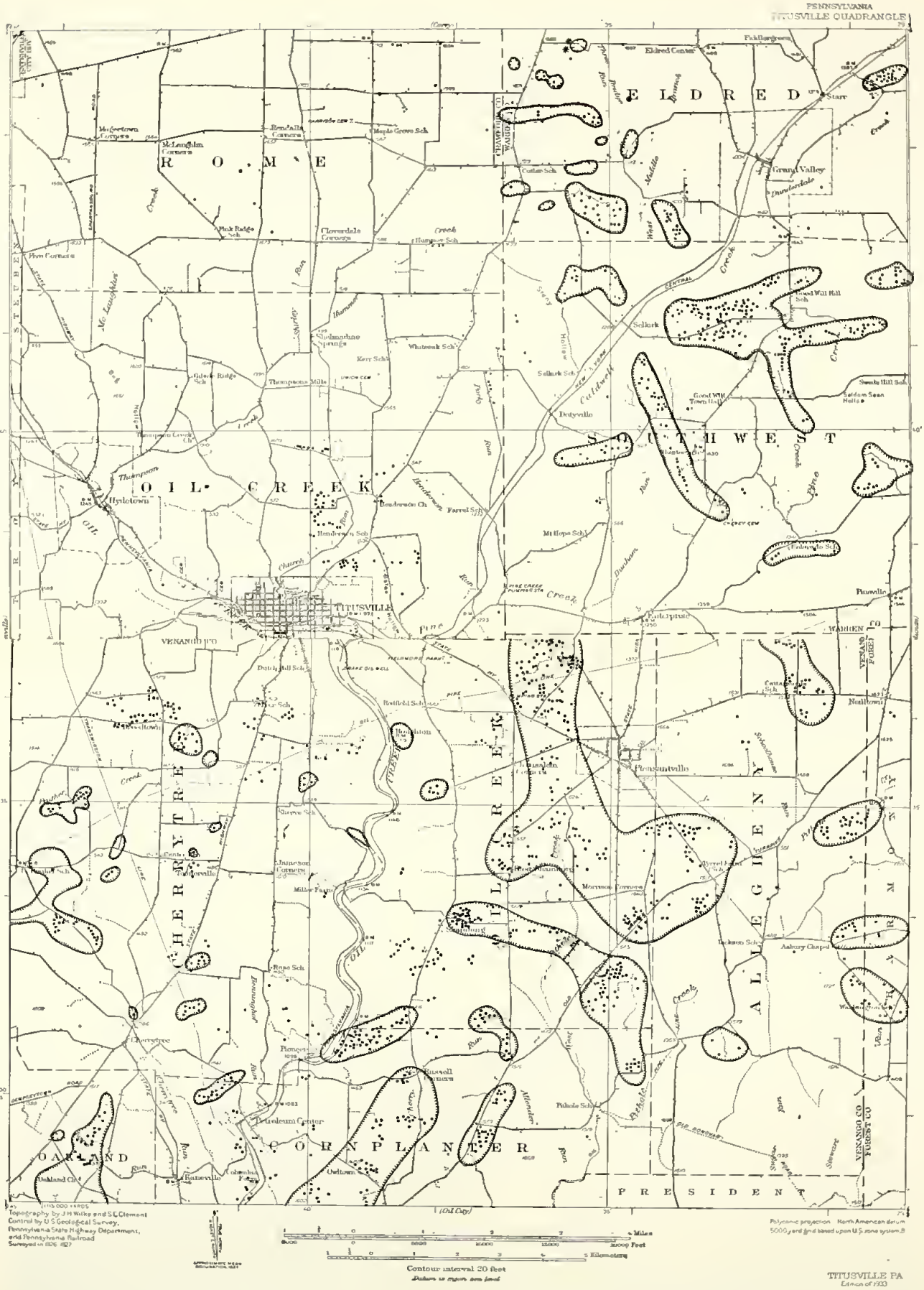


FIG. 4.—Map of Titusville Quadrangle showing areas producing oil from First sand. Limits of production shown by closely hachured lines; abandoned areas by widely hachured lines; wells whose logs record sand at this horizon and used in compiling this map, dots.

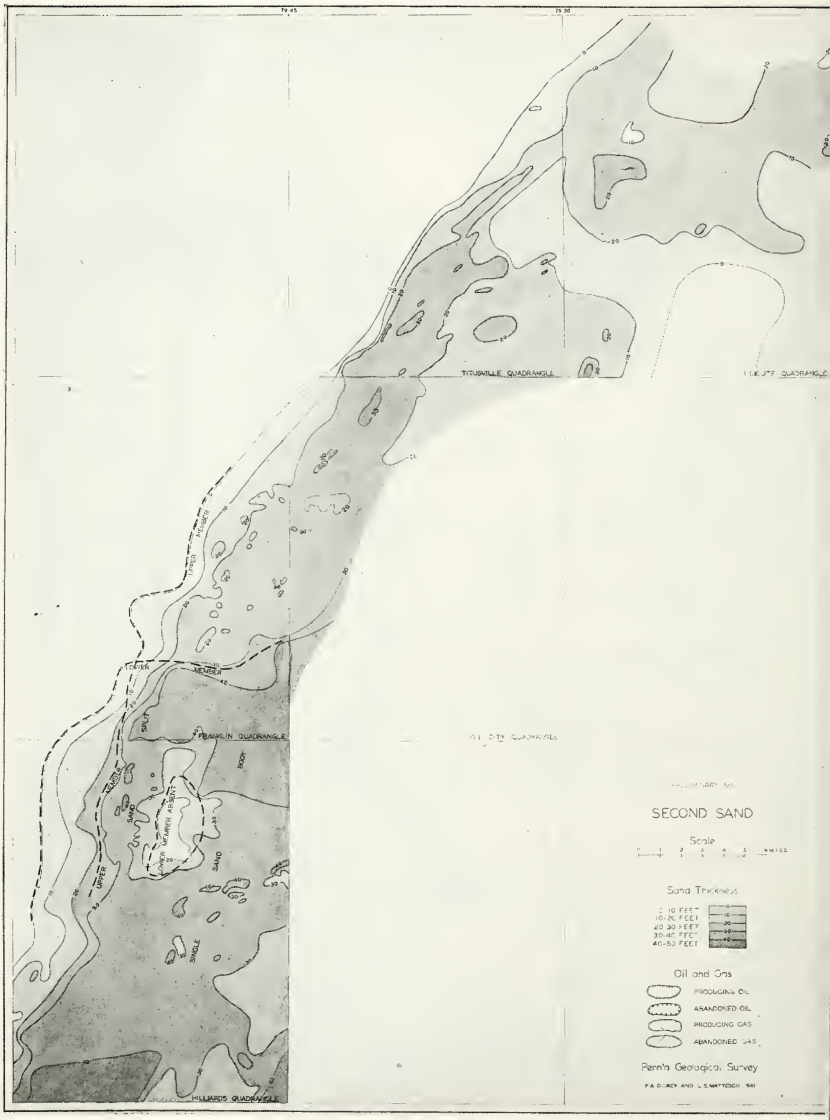


FIG. 5.—Map showing thickness of Second sand in Venango district.

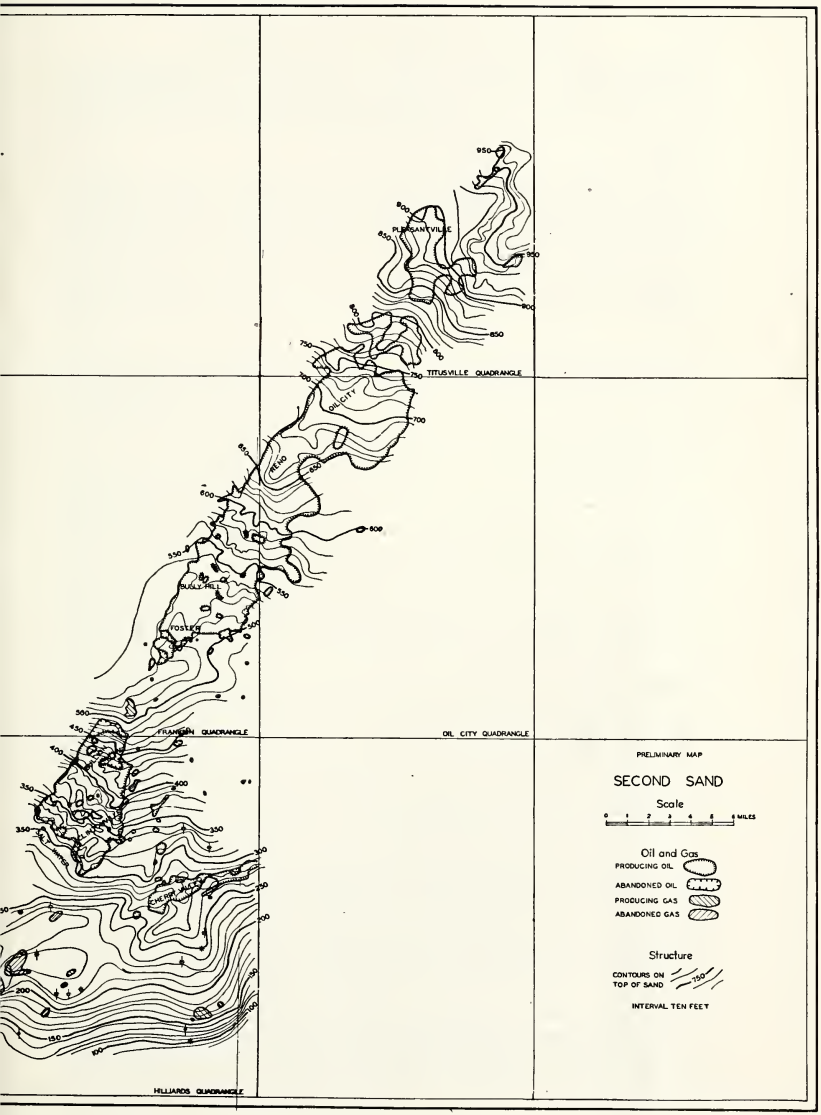


FIG. 6.—Map showing producing and abandoned oil and gas areas and structure of Second sand in Venango district.

Typically, the pay sand is a uniform, white, fine- to very fine-grained sandstone, but locally pebble layers occur at the top. Its average porosity is 20 per cent, and the average permeability probably less than 10 millidarcys.

Structurally, this pool is located on a very gentle southwest-plunging anticline, and the oil accumulation is apparently due in part to this fold. Down the dip, south and southwest of the pool, the sand is saturated with salt water. West and east of the pool, the sand is absent or tightly cemented. Up the dip toward the north, the pay member of the sand thins and grades into shale. This northern portion of the pool produces only gas.

The major development of the Clintonville-Bullion pool occurred from 1900 to 1910. Small quantities of gas—apparently little if any more than necessary to saturate the oil in the reservoir—were present. This gas is now completely exhausted, and the average production of the wells is about $\frac{1}{8}$ barrel of oil and an equal quantity of water per day.

Foster-Reno-Oil City pool.—The Foster-Reno-Oil City pool (Fig. 6) is the largest continuous oil pool in the district, covering about 30,000 acres. It is about 18 miles long and 3–4 miles wide. The producing sand of the pool is the upper member of the Second sand.

The northwest edge of the sand body is remarkably smooth and straight, striking N. 30° E. Toward the northwest the sand is very thin or absent. It thickens in a short distance from this edge toward the southeast, attaining a thickness of 20 feet in about a mile. For the next 3 or 4 miles southeast, the thickness ranges from 20 to 30 feet. Nearly all the oil productive areas lie within this belt. Farther southeast the sand does not thin appreciably, but becomes shaly and relatively impermeable. Some cores near the southeast edge of the pool show red and green sands and sandy shales, typical of a continental redbed series. Still farther southeast, in the southeast corner of the Oil City Quadrangle, the sand is nonproductive, but is in places recorded by the drillers as the "big red."

The northwestern boundary of the pool is clearly stratigraphic. The data available indicate that the southeastern boundary is also stratigraphic, and that the southern end may be structural. The southern boundary coincides roughly with the 510-foot contour on the top of the sand, south of which the sand contains water and is reported to be better cemented.

The first wells in this pool were drilled at Rouseville and Franklin in 1860. Since then the different parts of it have had several periods of abandonment and redrilling. Initial production of the wells was generally less than 50 barrels of oil per day. Much of the area has responded well

to air and gas drives, especially in the Oil City district. Cores from wells at Bully Hill and Reno are shown in Figure 7.

POOLS OF THIRD SAND

The Third Sand formation comprises the lower 75–110 feet of the Venango group. The two principal oil-producing sands are variously named in different parts of the district. The upper is here designated the Third Stray and the lower the Third sand, which is in accordance with the nomenclature of Carll.[5] The distinctive feature of the pools of this formation is their occurrence in long, narrow, northeasterly trending sand bars, which are in many places very pebbly.

Grand Valley-Triumph pool.—The Grand Valley-Triumph pool (Figs. 8 and 9) lies in the Titusville and Tidioute quadrangles in the northern part of the Venango district.

The productive sand of this pool is the Third Stray, which consists of long, narrow bars of thick sand, striking N. 30° E. in the northern part and N. 65° E. in the southern part. Between these bars the sand is thinner and more shaly, and is relatively unproductive.

The southernmost of the productive bar is called the Triumph Streak, and extends from its recurving eastern end near Tidioute 9 miles southwest, in few places more than 1,000 feet wide. The sand comprising this bar consists of a conglomerate composed chiefly of white quartz pebbles 2–3 millimeters in diameter, among which occur discoidal pebbles 1–2 centimeters in diameter. The larger pebbles in this bar occur most abundantly in the eastern, thicker part of it. In the western part the sand is only pebbly where its thickness is greater than 40 feet. The sand thickens eastward to a maximum of 120 feet in the central-eastern part of the bar. The thickening is by addition at both the top and bottom of the sand, but most of it occurs in the bottom where, in the thickest part of the sand, the Third Stray has combined with or cut through the lower Third sand.

The sand of the Triumph Streak thins within a short distance southeast but maintains its thickness toward the northwest. On the south it is entirely missing over a belt 2 miles wide. North of the western part of the Triumph Streak for 2 miles there are two or three similar bars, becoming progressively thinner. The sand of these bars is much finer, and consists of interbedded medium-grained sandstone, shale, and sandy shale, in which flat pebbles are commonly embedded. The shales in many places contain lumps of sand up to 1 inch in diameter and have irregular and crumpled bedding as indicated by cores. Farther northwest the bars become progressively thicker and the farthest one, at Grand Valley, is 60 feet thick and

[5] John F. Carll, *op. cit.*

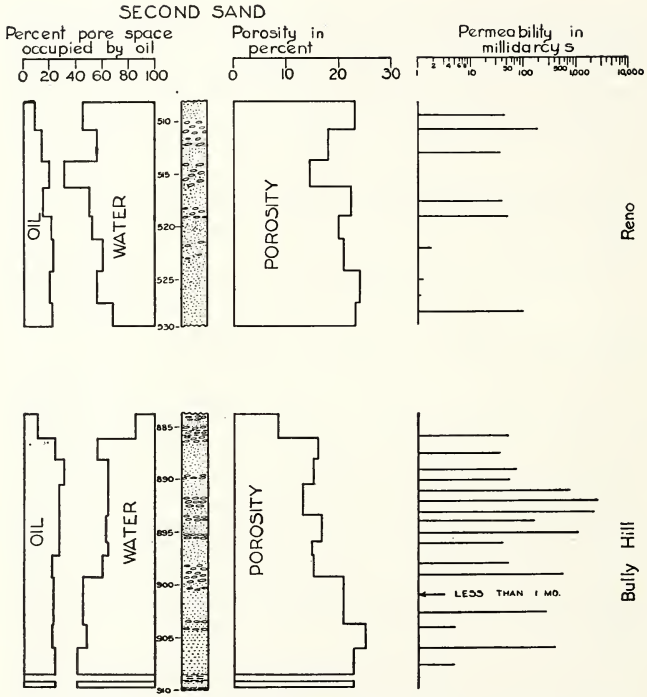


FIG. 7.—Profiles showing porosity, permeability, and oil and water content of Second sand in Foster-Reno-Oil City pool. (Permeability profile on logarithmic scale.)

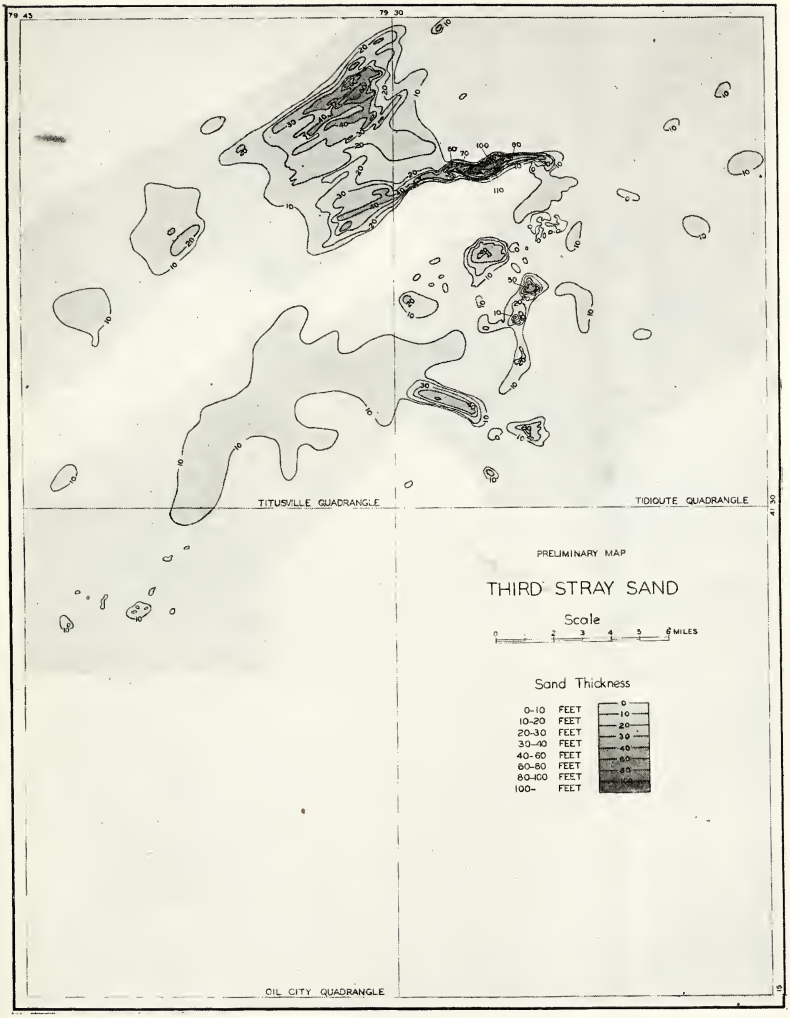


FIG. 8.—Map showing thickness of Third Stray sand in northern part of Venango district.

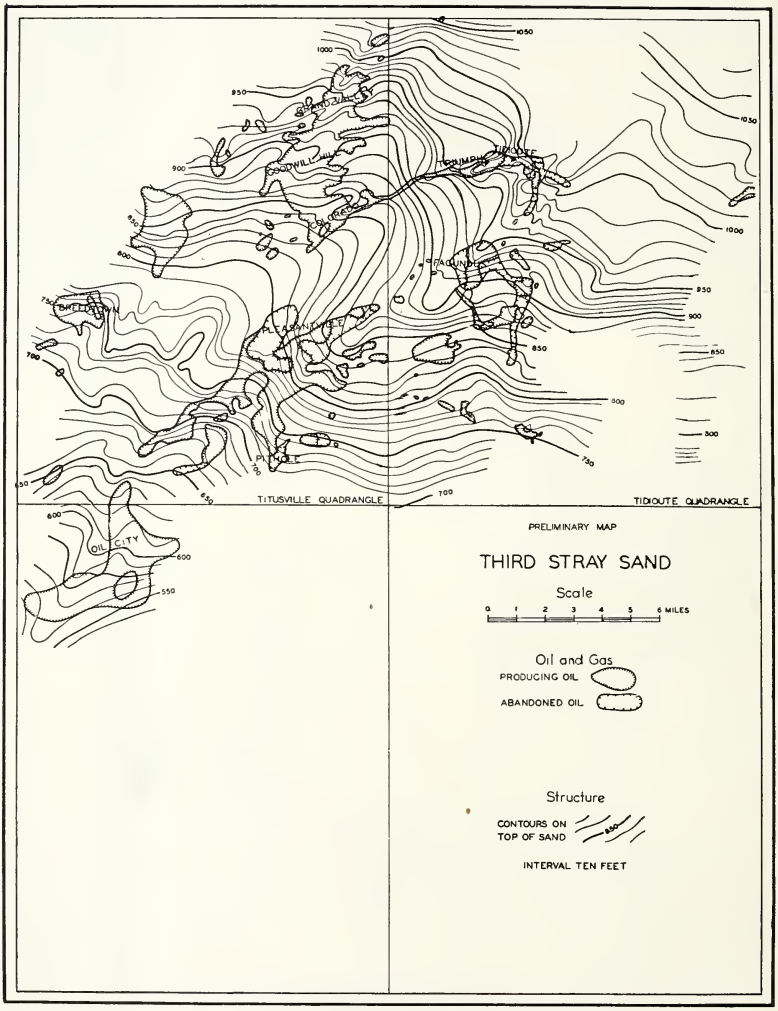


FIG. 9.—Map showing producing and abandoned oil areas and structure of Third Stray sand in northern part of Venango district.

very pebbly. Northwest of the Grand Valley bar the sand thins abruptly and then is missing. In the thinner belts between the bars, the sand is fine, shaly, and relatively unproductive. Southwest of the northern bars, and aligned with them, are two areas where the sand is present, but thin and relatively unproductive (Fig. 8).

The "structure" of the top of the Third Stray sand is shown in Figure 9. The sharp anticlinal form of the top of the sand in the eastern part of the Triumph Streak is the result of the thickening of the sand toward the center. Except for regional tilting and downward scouring, the bottom of the sand is essentially horizontal. The "anticline" extends upward with diminishing intensity through the overlying Second sand and Corry sandstone because of the compaction of the shales around the thick sand bar.

The Triumph part of this pool was discovered in 1860, the year after the famous Drake well at Titusville. It has had two periods of development. During the first period, which extended from 1860 to 1874, wells with initial oil productions ranging up to 1,000 barrels per day were drilled. During the latter part of this first period, water was entering the sand through leaky casings and unplugged wells, and by 1874 the Triumph area was abandoned. The second period of development started in 1898 and was characterized by the de-watering of the flooded sand. When de-watered the average wells produced 10–18 barrels of oil per day. The average present production is about ½ barrel per day.

The Grand Valley part of the pool was discovered in 1867, but was not largely developed until 10 years later. Initial oil productions of the wells were smaller than those of the Triumph Streak.

The oil from the Grand Valley and Triumph pools is dark green in color, and ranges from 42° to 45° A.P.I. in gravity. Core-analysis profiles from two wells about 300 feet apart in the Goodwill Hill portion of the Grand Valley pool are shown in Figure 10.

Shira Streak pool.—The Shira Streak (Fig. 12) is a long, narrow, northeast-trending pool in the Hilliards Quadrangle, in the southern part of the Venango district.

The productive sand of this pool, called the Shira sand, lies in the upper part of the Third Sand formation and is approximately correlative with the Third Stray of the Grand Valley-Triumph pool. In the Shira Streak it is medium-grained to pebbly greenish gray sandstone, 3–12 feet thick. It is overlain and underlain by dark gray shale. The sand reaches its maximum thickness in the central portion of the bar. It thins abruptly at the southeast edge of the pool, but is more continuous toward the northwest, where several outlying oil and gas pools have been developed

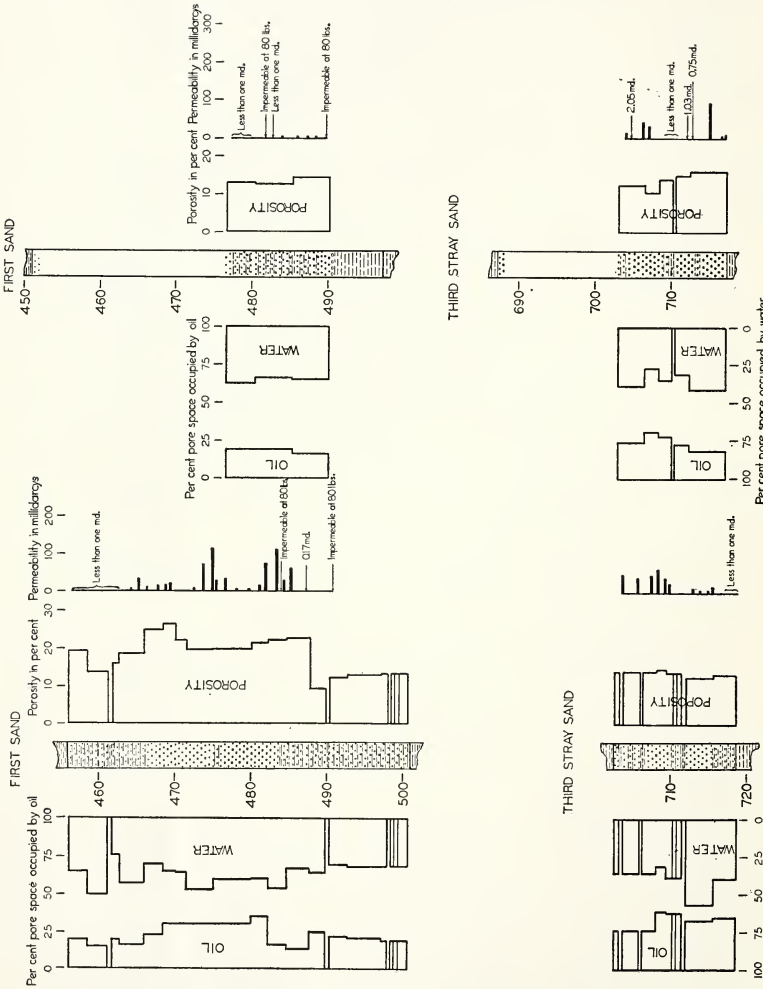


FIG. 10.—Profiles showing porosity, permeability, and oil and water content of First and Third Stray sands in Goodwill Hill pool at Reno and Bully Hill. (Permeability profile on linear scale.)

FIG. 11.—Map showing thickness of Shira sand.

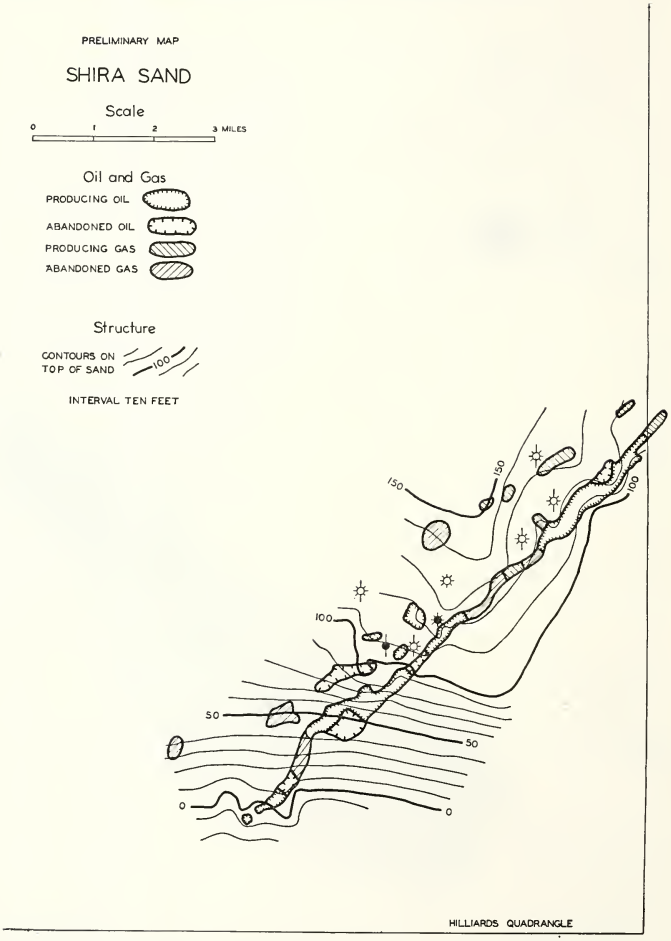


FIG. 12.—Map showing producing and abandoned oil and gas areas of Shira sand, and isolated wells producing from Shira sand in Hilliards Quadrangle.

in it. In the northeastern part of the bar, the topmost foot of the sand contains pebbles up to one inch in diameter and is gas-bearing. The oil pay sand is medium-grained and averages 8–10 feet in thickness (Fig. 11).

The structure of the Shira Streak is shown in Figure 12. It is noteworthy that the localization of this pool is independent of structure, but that the principal gas-producing parts of it are the updip northeast end and the central portion where the productive sand bar crosses a low southeast-plunging anticline.

Oil production from the Shira Streak started in 1893. Initially many of the wells flowed up to 100 barrels of oil a day. Many of the wells still produce a barrel per day. In the central gas-producing part, the wells initially produced 3–4 million cubic feet of wet gas per day. The original rock pressure was about 350 pounds per square inch. Air and gas drives on a small scale have been successful in this pool.

Church Run pool.—The Church Run pool lies in the Titusville Quadrangle in the northern part of the Venango district.

The productive sand of the Church Run pool is the Third sand, which lies at the base of the Third Sand formation, and whose top is about 35 feet below the horizon of the top of the Third Stray sand. In the central portion of the pool, near its western edge, the sand is more than 50 feet thick and very pebbly, some beds being unconsolidated gravel with pebbles up to an inch in diameter. Interbedded with this gravel are several beds of sandstone without pebbles, and a few beds of shale. Permeabilities in the coarser beds range up to 5 darcys. The sand cuts out sharply toward the west and within a mile becomes thin, shaly, and unproductive. Eastward from the thick zone the sand becomes progressively finer. The pebbles are confined to certain beds, principally at the top and bottom of the sand, and the sand consists of medium- to fine-grained white sandstone and sandy shale with permeabilities from 10–50 millidarcys.

The pebbly western part of the sand body continues northward from the central part of the pool $2\frac{1}{2}$ miles, then swings northeast $1\frac{1}{2}$ miles, and thence extends north as a narrow shoestring 4 miles beyond the limits of the map. Throughout its entire extent it has a smooth and abrupt western edge and thins more gradually, becoming shaly toward the east. The pebbles are abundant only near the western edge.

South of the central portion of the pool around Titusville, the sand body separates into several bars (Fig. 13). In general, the sand is pebbly in the thicker bars and finer-grained between them. The two easternmost bars pinch out and end toward the northeast, updip, and near their northern end produced mostly gas.

78° 45'
79° 30'
41° 30'
TITUSVILLE QUADRANGLE
TIDIOUTE QUADRANGLE

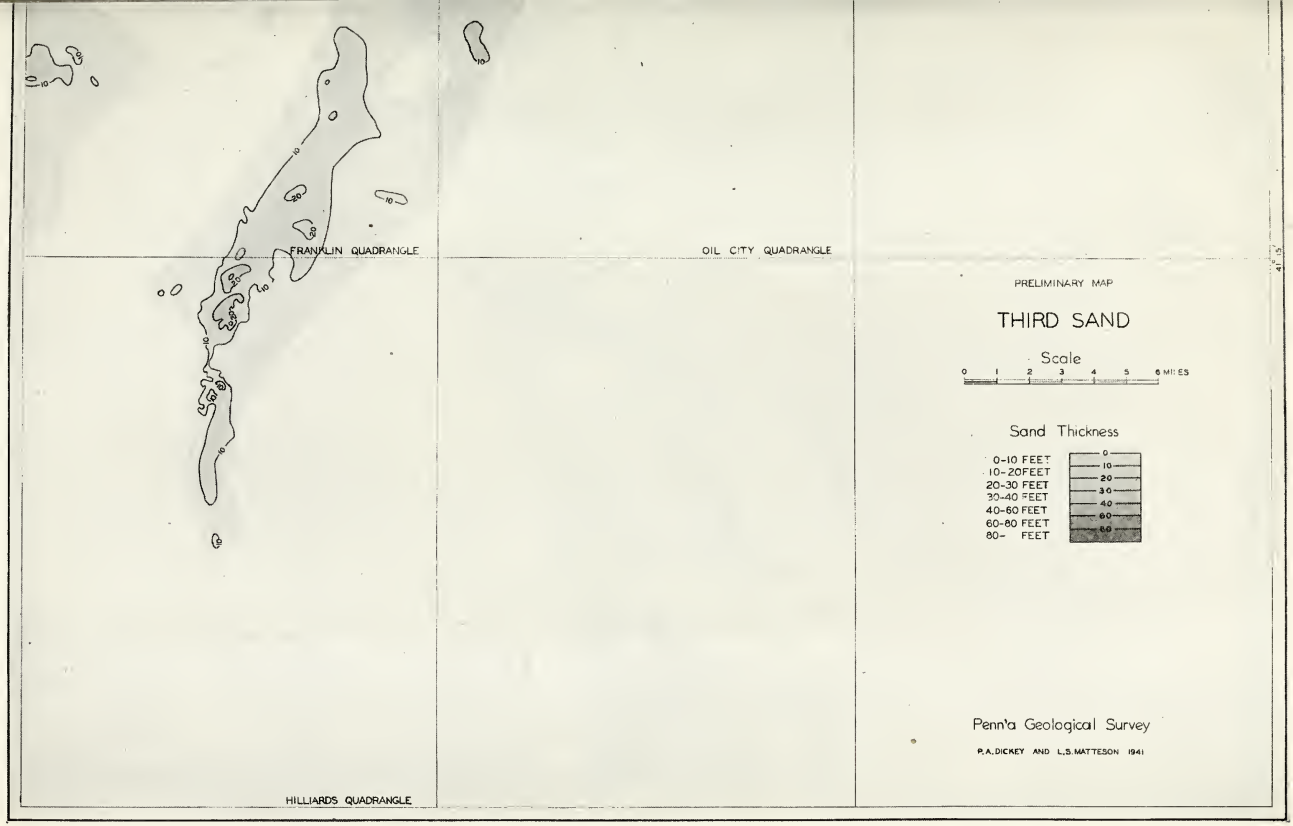
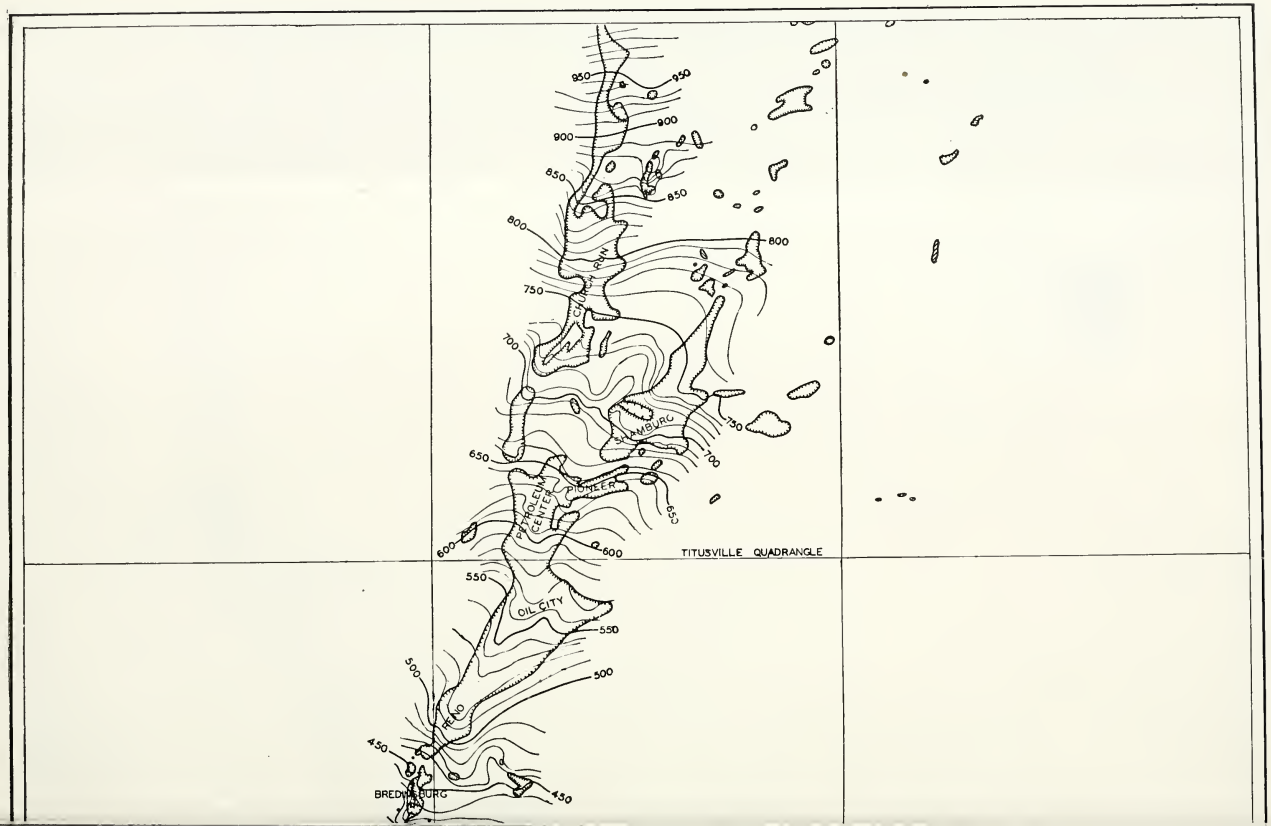


FIG. 13.—Map showing thickness of Third sand in Venango district.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BREDINSBURG
TITUSVILLE QUADRANGLE

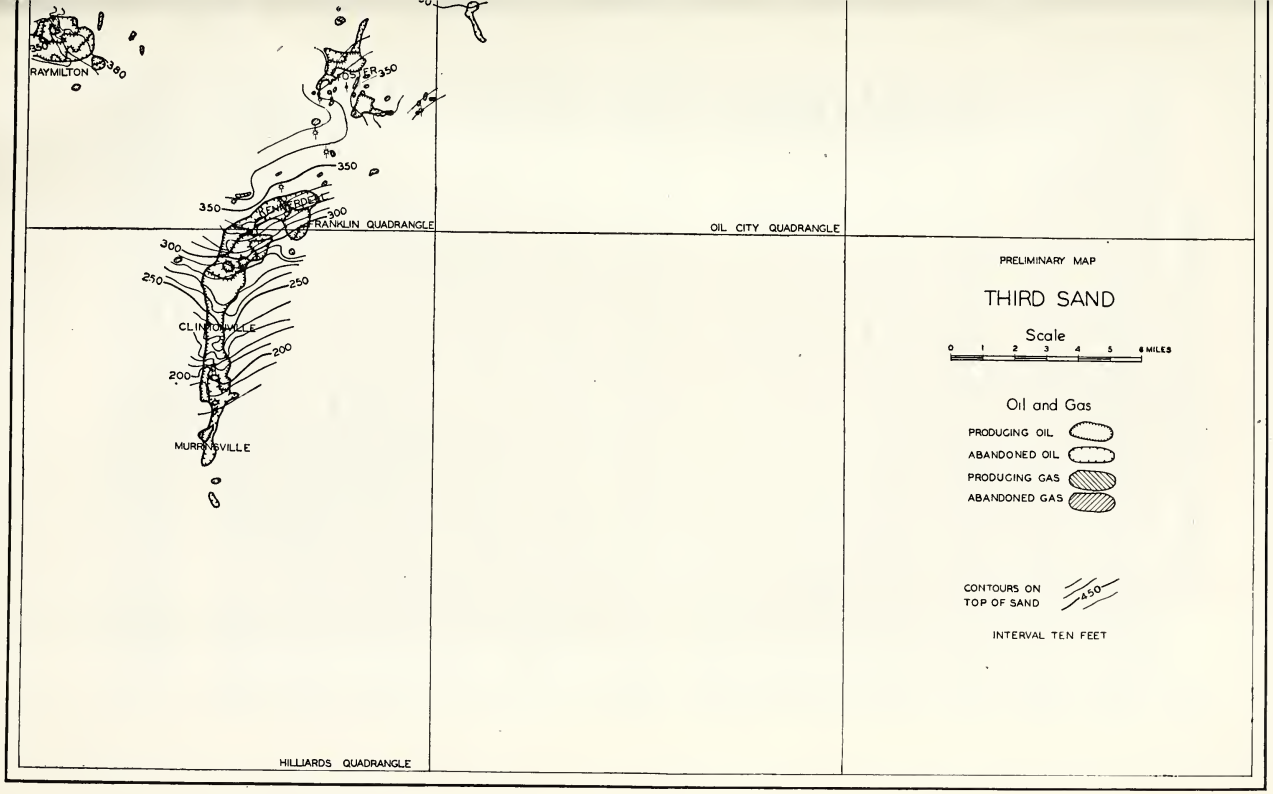

FIG. 14.—Map showing producing and abandoned oil and gas areas and structure of Third sand in Venango district.

Noteworthy in connection with the sand body of the Church Run pool are the two spots of thick Third sand lying about 1½ miles east of the main sand body. In the northern of these, at the Dotyville pool, the sand is 80 feet thick and pebbly throughout. In the southern spot, at Miller Farm, the sand ranges up to 75 feet thick, but is hard and shaly, although productive of oil.

Southeast of the Church Run pool lie the Petroleum Center and Shamburg sand bodies. These pools are not discussed in this paper, but the Petroleum Center pool consists of multiple, recurving bars of pebbly sand, between which the sand is hard, shaly, and unproductive. On the same trend toward the northeast lies the Shamburg pool, which is pebbly in the thick, central portion. It becomes fine sand toward the northeast, and ends near Pleasantville, but the trend continues as small, thin, rather shaly and relatively unproductive bodies as far as Grand Valley. It seems possible that the Petroleum Center-Shamburg-Pleasantville-Grand Valley trend of Third Sand bodies may be somewhat older than the bars of the Church Run trend, and may have been partly destroyed before and during the deposition of the latter.

The structure of the Third sand in the Church Run pool is shown in Figure 14. The anticlinal form of the top of the sand in the thick parts of the Church Run and Shamburg pools is depositional, and is due to either or both the original convex upper surface of the sand body, or the compaction of the shales below the thinner parts of the sand.

Oil production within the area here designated as the Church Run pool began with the first well in petroleum history; the Drake well, completed August 27, 1859, at a depth of 69½ feet. The producing sand of the Drake well was a thin stray sand in the lower part of the Riceville shale. As nearly as can be determined, the Third sand was first penetrated at McClintockville, in the southern part of the Petroleum Center pool, during the summer of 1860. There was active development of the Third sand near Titusville in 1861, but the influx of water through improperly cased wells caused the virtual abandonment of the pool before 1869. The pool has recently been redrilled and de-watered, and has responded successfully to air-drive operations.

Initial production of Third sand wells ranged up to 3,000 barrels of oil per day in the very open pebbly sands. The Third sand generally produces light green oil of 45° to 52° A.P.I. gravity.

Summary

The oil and gas pools of the Venango group in northwestern Pennsylvania belong to the general class of stratigraphic pools characterized

as sand lenses embedded in less permeable shale or sandstone. Although the pools are all of this general class, they may be further subdivided into three types which correspond to the three sandy formations of the Venango group.

The general geology of Pennsylvania shows clearly that during the upper Devonian, when the Venango group was deposited, continental deposition was taking place toward the southeast, and a shallow sea lay at the northwest. The shore line must have been in the vicinity of the productive sand bodies under consideration.

The first type of sand body, which is characteristic of the oil pools of the First Sand formation, consists of small, irregular, sand bodies trending or tending to be aligned in a direction approximately perpendicular to the ancient shore line. The productive sands are also very irregular in their vertical position, and cannot, at least with the data available, be accurately correlated between pools. In general, the sands are more pebbly toward the ancient sea and become finer inland. They may be channel sands, in, or near, delta distributaries from which littoral currents, or tidal and storm waves, have removed the finer material near the seaward end.

The second type, confined to pools in sands of the Second Sand formation, is characterized by extensive oil producing areas in more uniform, sheet-like sands, which pinch out abruptly northwest along a smooth and fairly straight edge parallel with the ancient shore line. In general these sands also are coarser near their edge toward the ancient sea, and become finer and red in color inland. Probably along-shore currents were active in spreading out and smoothing the contributions of the rivers into broad, low bars, behind which continental conditions prevailed.

The third type, corresponding with pools in sands of the Third Sand formation, is characterized by long, narrow, and in many places very pebbly, sand bars trending approximately parallel with the ancient shore line. In general these sands are thickest and most pebbly toward their seaward edge, and end abruptly in that direction. Typically, these sand bodies thin and become finer-grained toward the land, but in that direction other bars with similar trend may occur at approximately the same horizon. These sand bodies may represent off-shore bars preserved through subsidence to below the profile of equilibrium, or buried by increased contributions of material from the land, in a manner similar to that suggested by Brewer.[6]

The data thus far available on the Venango pools indicate that the oil

[6] Charles Brewer, "Genetic Relationship of Oil Reservoirs to Shoreline Deposits," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12 (1928), p. 602.

accumulated is the most porous and permeable material available. Within these sand bodies the gas, except that dissolved in the oil, moved into the higher parts of the sand or into the less permeable parts of it. The higher parts of the sand bodies are their north portions—up the regional dip—or, as in the Shira Streak, where the sand bar is crossed by a low fold, or, as in parts of the Triumph Streak, the depositional upper curvature of the top of the sand. Where the sand is sheet-like, as the Second sand at Clintonville, edge water accumulated down the dip. More commonly, however, the major water accumulation was in the finer sand, apparently through capillary adjustment. These finer sands are the more thoroughly cemented and the gravel beds are comparatively unconsolidated. The data suggest that the lack of cementation in the coarser sands may be due to the early entrance of oil into them, although doubtless everywhere some water remained.

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